Chapter 18
Educating the Post-Fukushima Nuclear Engineer

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Abstract While the Fukushima Daiichi Nuclear Accident shook the community of nuclear engineers, it had a special significance for nuclear engineering students. What were they supposed do? How should they and could they answer questions about nuclear safety? What about their future opportunities? The incident caused many students to question their deepest convictions about all things nuclear and opened up new questions about their social responsibilities. This chapter looks to the history of nuclear engineering education to provide context for the discussions that took place during the summer school. Historically, students have seldom had opportunities to engage the socio-ethical dimensions of their work. The summer school offers evidence that today's students are actively seeking new analytical skills and different ways to conceptualize the socio-ethical complexity of nuclear engineering problems. Moreover, students are poised to play a key role in shaping much needed curricular reforms.

Keywords Education · Ethics · Collaboration · History · Interdisciplinary · Students · Societal role

18.1 Introduction

What is the role of the nuclear engineer and how is it learned? Motivated by the Fukushima Daiichi Nuclear Accident, the 2011 Advanced Summer School of Nuclear Engineering and Management with Social-Scientific Literacy provided an occasion to reexamine the role of nuclear engineers. By reflecting on the content and context of the Summer School, this chapter examines how the education

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of engineers has shaped their societal and professional roles and also their understanding of these roles. The Summer School raises questions about what kinds of educational changes are needed to ensure that nuclear engineers are better equipped to deal with the inherent challenges of the Post-Fukushima world. The events and outcomes of the Summer School provide evidence in favor of curriculum reform. Students don't just need the different approaches offered by the social sciences—they want to learn them. Historically, there has been very little space in the curriculum for students to think about nuclear engineering more broadly, little tolerance of positions that question the safety and necessity of nuclear power, and limited resources to facilitate an informed discussion about these topics. Despite these challenges, students are actively seeking alternative ways to address the multidimensional Post-Fukushima problems that are not amenable to engineering's traditional utilitarian reasoning and optimization studies.

The engineering community has a long-standing interest in educational improvement. In 1893 engineering was one of the first professions to institutionalize its commitment to education with the establishment of the Society for the Promotion of Engineering Education (SPEE). Founded as part of an effort to standardize an engineering curriculum that stressed fundamental concepts in science and math rather than practical know-how, the SPEE identified engineering colleges as the right place for engineers to receive their training [1]. Yet despite engineering's professional commitment to educational improvement, recent research demonstrates that engineering education is extremely resistant to change [2, 3]. Studies show that new pedagogical approaches are rarely implemented on a larger scale because of institutional barriers including financial constraints, class size, classroom space, technology, instructional staff time, and skepticism of whether student learning will really improve [4]. Compounding these hurdles are the hierarchy structures, reward systems, ideologies, and the general curricular organization of engineering education [3]. Historical analyses, for example, suggest that global-scale catastrophic events are needed to initiate educational reforms [5]. Although it is unfortunate that real change can only be justified and implemented in the aftermath of significant geopolitical events, this historical perspective helps us to make sense of how the nuclear community is responding to the Fukushima Daiichi accident; the time is finally right to transform the education of nuclear engineers.

Fortunately, there are many resources that are available to support this transformation. Today, engineering education is an emerging discipline in its own right, complete with PhD programs, journals, and conferences [6].[1] There is a growing community of scholars who are committed to advancing education through research, whose efforts are supported by a range of funding institutions, including the National Science Foundation, which invests millions of dollars into engineering education endeavors [7]. There is also a growing group of scholars who are committed to developing

[1] For example, Virgina Tech, Purdue University, and Clemson all offer advanced degrees in engineering education. The Journal of Engineering Education, PRISM, Advances in Engineering Education, Science and Engineering Ethics, The Bridge, and the European Journal of Engineering Education are all dedicated to issues regarding engineering education.

strategies to overcome the hurdles that challenge the effective implementation of innovative educational initiatives (e.g. [6, 8]). So, while the Summer School is subject to many of the constraints that obstruct educational change, it can also draw on the resources of scholars who work at the intersection of engineering, education, and the social sciences. Building on this scholarship, this chapter emphasizes the importance of involving students as partners in envisioning and implementing curricular reforms [9, 10]. As the nuclear community imagines new societal roles for the next generation of nuclear engineers, it is essential to consider students as key community members who hold unique perspectives that should contribute to shaping future educational programs and opportunities.

This chapter offers a brief history of nuclear engineering education in the U.S. to contextualize the discussions that took place at the Summer School and to provide a better understanding of current curricular gaps.[2] One of the central challenges is to understand how the identification and articulation of these gaps differs between students and faculty members. A recent study of the engineering undergraduate community, for example, revealed the existence of important differences, especially regarding how students experience engineering ethics. Whereas faculty members think that they are presenting ethics in a nuanced and interesting manner, students describe learning ethics as a set of rules to be followed [11]. Recognizing that students' interpretation and experience of the curriculum matters, is an important step toward implementing effective educational changes. By drawing attention to student experiences, this chapter proposes that the nuclear curriculum would benefit from a pedagogical shift away from the formal lectures and quantitative reasoning style that usually dominate classroom instruction in order to make room for more discussion-based learning as a way to promote critical reflection through dialogue. In addition to learning through discussion, today's students are ready to take the socio-ethical dimensions of their work seriously. Doing this requires more than just exposure to the social sciences [12]. Students require opportunities and time to effectively engage with and practice new approaches and analytical techniques. Exposure to and practice with alternative research methods would help to lay the foundation for productive collaborative research opportunities with non-engineering scholars.

18.2 A Brief History of Nuclear Engineering Education

Engineering has a long history of educational change. Throughout the twentieth century educational reformers in the U.S. have sought ways to reach the right curricular balance between practical design and basic science and math, while also

[2] Ideally, the chapter would present a comparative account of nuclear engineering education in both the U.S. and Japan. However, I had access to substantially more literature regarding the American context, particularly because my search was limited to material that was published in English. For this reason, I was unable to locate information about nuclear engineering education in Japan, with the exception of a paper by [11], which does not include historical information.

making room for the social sciences and humanities [13–15]. An overemphasis on engineering's scientific foundations became especially prominent in the U.S. after World War II alongside the emergence of nuclear engineering [14, p. 285]. New funding opportunities for academic engineering research were created by an influx of post-World War II funding. Massive, unprecedented amounts of federal money from the military and the Atomic Energy Commission (AEC) triggered educational and institutional reforms that emphasized science over practice while pushing the humanities and social sciences aside [14, p. 289]. Funding from the military and the AEC favored research on jet propulsion, rockets, computers, and nuclear power, and provided institutions with enough money to support entire graduate programs, including new facilities and equipment [14, p. 289]. The educational approach exemplified in these research-heavy fields, such as nuclear engineering, stood in sharp contrast to the apprenticeship programs that had provided the training for the majority of engineers throughout most of the nineteenth century [1].

In the 1950s, the AEC began sponsoring summer seminars on the new "glamour field" of nuclear engineering that was beginning to materialize in conjunction with the development of nuclear energy [1, 16]. Efforts to formalize nuclear engineering education in the U.S. followed. Physicists, chemists, and electrical engineers populated the first programs, reflecting the important role that these disciplines had played in the Manhattan Project. Early curricula emphasized nuclear physics, the analysis of neutron transport, and the materials needed for nuclear weapons. In step with the commercialization of nuclear power, the first undergraduate programs in nuclear engineering emerged in the 1960s and incorporated elements of reactor science [16, pp. 1, 16]. Strong national support of civilian nuclear power during the 1960s spurred the growth of the nuclear industry. New opportunities arose for nuclear engineering professionals as plants anticipated increased electricity demand. By 1975, the U.S. had eighty nuclear engineering departments. Growth was fueled by developments in the nuclear power industry and by the substantial quantity and quality of fellowships and funding that was available through the AEC. In addition to supporting students, the AEC paid for nuclear reactors that were dedicated for educational and research purposes—a contribution that reflected their commitment to promoting the development of civilian nuclear power.

The expansion of nuclear engineering did not slow until the late 1970s when concerns about the environment and radiation shaped a changing nuclear market that was characterized by plant cancellations and closures. The accidents at 3 Mile Island (1979) and Chernobyl (1986) fueled pubic concern about nuclear power [16, p. 16]. By the 1980s there was growing distress in the nuclear engineering community that downward trends in student enrollment, in both undergraduate and graduate programs, warranted a comprehensive assessment of the state of the field. Many institutions wanted to learn more about these negative trends with the aim of identifying possible solutions, including the American Nuclear Society (ANS), the Institute of Nuclear Power Operations (INPO), the Nuclear Engineering Department Heads Organization (NEDHO), and the U.S. Department of Energy

(DOE). In response, the Energy Engineering Board of the National Research Council conducted a study to analyze: the declining numbers of U.S. university nuclear engineering departments and programs; the problem of aging faculty; the mismatch between curriculum and the needs of industry and government; the availability of scholarships and research money; and the increasing ratio of foreign to U.S. graduate students [16, p. xi].

The report's investigation centered on addressing whether current educational programs were "appropriate for future industry and government needs" and asked "What skills and education may be required for the next generation of nuclear engineers?" The committee conducted interviews and surveys across academia, industry, and government to assess the "history, status, and future" of nuclear engineering education and concluded that the curriculum was "basically satisfactory" [16, pp. 2, 5]. Rather than exploring possible curricular reforms, the report focused on strategies for dealing with the field's research shift away from new reactor technologies and with its aging faculty members. The only suggested curriculum adjustments were modifications to improve students' communication skills, and to increase their general knowledge of reactors and of the biological effects of radiation [16, p. 5].

Satisfaction with the nuclear engineering curriculum in 1990 was short lived. By 1998 NEDHO issued the report *Nuclear Engineering in Transition*: *A Vision for the 21st Century* that recommended a number of more substantial curricular changes to aid the profession through "a period of transition" in which the focus was shifting away from nuclear power to embrace a broader range of nuclear science applications [17, p. 1]. Both reports assuredly concluded that maintaining nuclear engineering as a distinct discipline was vital to the future success of nuclear energy programs. The program's curriculum was described as uniquely preparing students to address the complexities of nuclear technologies [16, p. 3]. Nuclear power and nuclear engineering were portrayed as interdependent in both the past and the future. Considering the ongoing international impact that Fukushima is having on the future of nuclear power, it is prudent for nuclear engineers to reassess their roles and to build the skills that they will need to address the challenges ahead.

Driven by the concern that engineers were not prepared to meet the demands of the future, the National Academy of Engineering published a series of reports in 2004 and 2005 titled *The Engineer of 2020*: *Visions of Engineering in the New Century* that emphasized the need to refocus and reshape the engineering learning experience to meet societal goals. The report includes suggestions about how to restructure programs, reallocate resources, and refocus faculty and professional time and energy while emphasizing the need to keep the social sciences and humanities in the curriculum [18, p. xi]. The report foresaw the ideal engineer of 2020 as someone with an understanding and appreciation of the impact of engineering on "sociocultural systems" and also the value of non-engineering jobs. As a creative leader, the future engineer would remain knowledgeable in math and science, but their design visions would be grounded in the social sciences, humanities, and economics [19, pp. 48–49]. The report, however, was researched and published well before the events at Fukushima. Would this hypothetical engineer of 2020 have been equipped to deal with the challenges of post-Fukushima nuclear engineering? Looking more closely at some of the discussions that took place at the Summer School points to unanswered questions that signify the need for more radical reforms.

18.3 Post-Fukushima Questions and Answers

Engineers are celebrated for their role as superior problem-solvers who depend on math and science to make rational, accurate decisions, and ultimately to create new things [20]. Increasingly, scholars are raising questions that challenge the engineers' role, including: For whom do engineers work? How do engineers select the problems to solve? Which problems are not worth engineers' investment, and which are beyond the expertise of the engineer? Who benefits? [20, p. 26]. Since their role is traditionally in the problem-solving domain, engineers tend to stick to solvable problems, wherein a problem's solvability is directly related to the amount of *quantitative* information that can be gathered about it. Trained to approach problems with the tools of optimization studies, cost-benefit analysis, and risk analysis—engineers depend on manipulating numbers to obtain objective results. One of the core issues with the problems surrounding Fukushima is that the answers rely on more than numbers. This was a concern that was raised repeatedly throughout the Summer School. Much time was devoted to searching for ways that nuclear power could be justified without weighing its costs and benefits in numerical terms. In this sense, the problems are distinctly non-engineering. And yet, they involve a technology—nuclear power plants—that are beyond comprehension to the majority of those outside of the nuclear engineering community. What then, is a reasonable and desirable approach to take when weighing the analyses and recommendations of nuclear engineering experts alongside the views of the rest of the population? This question, in particular, seized the Summer School participants' attention.

Discussions about the challenges of communicating the safety of nuclear power persisted throughout the week. These discussions largely focused on public communication, safety, and trust, which were the most salient issues to the participants, perhaps because communication seems within the nuclear engineers' realm of responsibility. In contrast, it was more difficult to have "productive" discussions about issues that were more squarely located in the social sciences, including conflicts of interest, troubling institutional arrangements, and different ideas about the concepts of rationality, expertise, and risk. One of the professional norms that became evident during the Summer School was that engineers learn that it is irresponsible, and perhaps even impossible to make the "right" decision without adequate knowledge of the scientific facts. This prioritization of factual knowledge was evident in the organization of the summer school. For example, the first day of the program involved a series of content-heavy lectures that offered rigorous scientific analyses of radiation, reactors, and regulations. Starting off the program with these lectures implicitly communicated its priority to the students; it was important to know this information first. Throughout the day, the discussions considered how this kind of scientific information was and was not communicated to the public. Many engineers felt that it was their responsibility to do some of this public communicating and also to act as information gatekeepers. One student, for example, remarked that it was irresponsible to risk panic by releasing data to the public before professionals were able to act on it.[3] Students also expressed that their role was to model and measure the available data in order to bound problems, but also expressed concerns about how and what to measure.

The second day included lectures on the future of reactor design and on the ethics and "safety culture" of nuclear power plants, which fueled a discussion about engineering's reliance on utilitarian reasoning. The first presentations from social scientists began midweek, in which new ways of thinking about the Fukushima Daiichi Nuclear Accident were introduced. Students were asked to reconsider the challenges of building interdisciplinary awareness across engineering and the social sciences, but also across the more specialized fields within engineering and science (e.g., between nuclear engineers and climate scientists). The social scientists provided students with examples of how to study the institutional and organizational factors that are shaping the ongoing events at Fukushima, including the arrangements between regulatory bodies, industry, government, and academia. Instead of framing the accident in terms that are familiar to engineers, such as safety culture, students were encouraged to consider how social conditions and institutions had shaped the definition of safety. A historical perspective, for example, shows us that nuclear power is judged with great severity, in part because of the public fear of radiation. For this reason, analyses that compare the risks of nuclear power with those of motor vehicles or airplane crashes are not always meaningful. Looking back on the events surrounding 3 Mile Island reminds engineers that severe accidents will happen and that it is important to communicate about them openly and critically.

After a day of social science immersion, students had an opportunity to begin in depth discussions with one another. This provided an important space for students to identify issues beyond their professors' gaze. For engineering students, this is a necessary exercise to facilitate a pedagogical shift away from lecture-style learning, and to allow each student to develop a perspective and voice that is different than their professors'. A recent study of the undergraduate experience of engineers as compared to students in computer science, science, technology, math, arts and humanities, social sciences, business, and other majors determined that engineering students spend considerably more time preparing for class and have the highest number of credit hours, many of which are spent in lecture [21]. Engineering students quickly learn how to intake and apply the information from lectures wherein the focus is on finding the most efficient way to complete problem sets rather than critically engaging each professor's views.

[3] To protect the privacy of the Summer School's participants, comments are not linked with individuals.

In contrast, students at the Summer School were expected to participate in a discussion that involved deep reflection about apparently unanswerable questions. Students were instructed that although discussion and reflection would likely feel unfamiliar to them, and perhaps even unproductive, it was something that they owed to the society that had funded their work. After hearing from the social scientists, students were asked to break off into smaller groups in order to further discuss the issues that most concerned them. The process of group formation was not obvious, and students spent much time brainstorming the issues that interested them before they cohered into groups. But even after this coherence, the students decided to remain in close proximity so that they could move from group to group. Many of the students shared common concerns and valued the opportunity to learn from their peers.

On the fourth day of the Summer School students had an opportunity to learn about how engineering ethics was largely imported to Japan from the U.S. in the late 1990s. Comparing the United States and Japanese codes of ethics reveals that Japan does not emphasize engineering as a profession. In Japan, most engineers' identities are linked to their place of employment rather than with the general engineering profession. Students were encouraged to think about how these differences might have shaped the Japanese response to Fukushima. In response, students began to discuss who belongs to the engineering profession. Who counts as a member of the engineering community? U.S. students also admitted that they had never read the U.S. engineering code of ethics. The discussion turned to explore the role of the code—is it for students, or advanced professionals? It was pointed out that mid-career engineers had little time or incentive to discuss ethics and furthermore, that the relationship between ethics and regulation were unclear. Students were asked to think about the role of nuclear power in long-term energy planning. Again, the discussion turned to questions about how to deal with "irrational" decision-making. Engineers felt strongly that it was their responsibility to keep public discussions about energy on "rational grounds" by providing important data about the costs and benefits of investing in different energy technologies. Increasingly it became clear just how uncertain the future of nuclear energy had become in the wake of Fukushima.

Throughout the week, students had been breaking off into smaller groups to discuss the problems and questions they found most concerning and interesting. On the final day, students were asked to present the findings of these discussions. Students felt that they were in a transitional moment. They knew that they wanted and needed something different, such as skills that could enable them to communicate with different audiences and contribute to different discussions. The nuclear engineering students were clearly open to new ways of thinking and recognized the importance of building these skills. Students were especially interested in developing skills that would enable them to move beyond focusing on cost-benefit analyses.

Although some students expressed frustration with the program's lack of clear answers, it was evident that their discussions had generated important new perspectives that moved the conversation in different directions. For example, students recognized that it would be unproductive to try to evaluate the Fukushima events without first learning more about the history of nuclear power in Japan. In addition, students suggested that important insights might be drawn from conducting a comparative analysis of the different assumptions regarding the safety of nuclear power that were held in the U.S., Europe, and in Japan.

Different international perceptions of nuclear safety inform the nuclear engineer's role in each country. Students were attracted to the Summer School for a variety of reasons. Some were generally committed to the importance of nuclear energy in the future and were interested to learn more about how and why the events at Fukushima had jeopardized nuclear energy's reputation. Others were not clearly advocates of nuclear energy, but wanted to make sure that it was used correctly in the future, especially in developing countries. Still others were drawn to nuclear engineering by the lack of good planning that they had witnessed in their home countries and hoped that attending the Summer School would provide them with important information to help their home countries incorporate nuclear energy responsibly. The diversity of interests and concerns that attracted students to the Summer School point to the wide-ranging role of today's nuclear engineer. Whereas nuclear engineers in the past were expected to be advocates of the nuclear power industry, students today are drawn to the field for a diversity of reasons and will undoubtedly play different roles. One clear role does not exist. Each nuclear engineer is responsible for shaping his or her own role.

As they tried to gain a better understanding of the engineer's problem solving approaches, students started to ask how others solve problems. They wondered if everyone was doing their own version of cost-benefit analysis, or if there were entirely different approaches available. The shortfalls of cost-benefit analyses became clear as the students wondered if there was any value in comparing things that were fundamentally incommensurable. Students pointed out that it was paternalistic to label an individual as irrational and noted the shared societal value of respecting a diversity of perspectives. The trouble with many discussions about benefiting the public is the inherent assumption that the public is homogeneous. Students want to find ways of identifying and communicating their assumptions. They are looking to social scientists for help with these problems.

18.4 Building Sustainable Interdisciplinary Bridges

Engineering education has received much scholarly attention from historians of technology, in part, because looking at education offers a window to how the societal roles of engineers have been communicated both explicitly and implicitly [22, p. 738, 23]. Engineers' understanding of this role is shaped by their assumptions about how science and technology work. This is because ideas about the relationship between science, technology, and society underlie the engineers' decision-making process. Since the turn of the twentieth century, these ideas have been informed by engineers' educational experience of reading texts about the inevitability of technological progress. [15, p. 754, 22, pp. 740–741]. Although the notion of inevitable technological progress is widely shared within the engineering community, it is deeply problematic to many social scientists. The fact that engineers' predominant understanding of technology is counter to that of social scientists raises questions about how engineers are exposed to the social sciences and points to a need to develop new learning opportunities.

Is there anything new to try? In the 1960s, there were substantial initiatives to incorporate the humanities and social sciences into the engineering curriculum. One pedagogical approach involved describing why technology's adverse affects on civilization required engineers to learn the humanities: the humanities would help engineers to avoid technologies' negative consequence. Another method gave social scientists the task of developing courses that could make engineers into expert policy-makers, without substantial curriculum reform. The third approach was to make engineers more introspective by assigning readings that would allow them to use the social sciences and humanities in the same way that they used mathematics and science. During these 1960s reforms, historians of technology became embedded in the engineering culture as they sought to make the humanities relevant to engineers in a way that made them effective managers of technological progress. Although the programs did not last, the impression that engineer's should manage technology's inevitable progress remains powerful today [15]. The Summer School seeks to offer something new: a collaborative opportunity that brings engineers and social scientists together. Collaborative learning and knowledge production, however, is not easy [10, 24].

Although the social sciences are continually recognized as an important aspect of the engineering curriculum, they are often interpreted by engineers as a way to learn how to "put yourself in another person's shoes," as one Summer School participant described. This understanding, however, misinterprets much of the social science scholarship, which develops concepts and analytical approaches to better understand science, technology, engineering, and society. For example, historians, sociologists, and philosophers all use different methods and theories to do their work. Some studies are highly empirical and descriptive and others are more conceptual. Some studies aim at explanation while others seek normative evaluation, or ethical analysis. Some focus on the theories and methods of science and engineering, while others pay closer attention to social forces [25, p. 5]. Instead of trying to "put oneself in the other's shoes" ethicists and philosophers of science, in particular, have emphasized the importance of trusting the authority, perspectives, and opinions of the people who are not in a position of power [26].

The social sciences and humanities are steadily described as a necessary part of the engineering curriculum, but are mostly viewed as a way to teach students communication skills. Students often perceive these sorts of courses as irrelevant requirements that must be fulfilled. Engineering faculty are hesitant to give too much time to such courses, and thus they usually remain a distinct add-on, non-critical, non-technical course in an otherwise integrated curriculum [15, p. 754, 27]. The Summer School is a distinct departure from this history, but also constrained by its legacy. While it does provide students with an intense social-science immersion opportunity, the course is not part of the core curriculum. The social sciences are relegated to the summer, in part, because there is little time to engage them during the regular semester. When students finally find themselves at the summer school, they struggle with the unfamiliarity of open-ended discussions even while they recognize the limitations of lecture-style instruction. The Summer School experience is a distinct outlier in their educational experience—a feature that magnifies its challenges and successes.

18.5 Conclusion

Histories of engineering education have examined how the training of engineers positioned them with respect to larger societal roles [22, p. 739]. In the post-Fukushima world, nuclear engineers are positioned to assume a new social role. In fact, this is what they are being instructed to do. Students are learning from their professors about the widespread severity of the Fukushima events on the future of the nuclear industry. Students were told that they were at the Summer School to learn how to communicate in a global society. They have been charged with rebuilding the trust of the nuclear engineering community; a task that they have inherited, like it, or not. They are being asked to think and act differently—to challenge their professors, to challenge all of their assumptions, to find their own answers. Students are hearing that it is time to expand the scope of nuclear engineering. Programs are being restructured. The Summer School provides those that are doing the restructuring with good evidence about: the value of discussion as a tool to facilitate critical reflection; the importance of collaboration for enabling engineers to inhabit new societal roles; and the necessity of incorporating student perspectives during curriculum reforms in a way that allows students to become active participants in shaping the future of nuclear engineering.

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